

TITLE OF THE INVENTION

PHOTOMASK, METHOD OF MANUFACTURING A PHOTOMASK, AND  
METHOD OF MANUFACTURING AN ELECTRONIC PRODUCT

CROSS-REFERENCE TO RELATED APPLICATIONS

5           This application is based upon and claims the  
benefit of priority from the prior Japanese Patent  
Application No. 2002-199918, filed July 9, 2002, the  
entire contents of which are incorporated herein by  
reference.

10                           BACKGROUND OF THE INVENTION

1. Field of the Invention

          The present invention relates to a photomask  
having a desired flatness, a method of manufacturing  
such a photomask, and a method of manufacturing an  
15       electronic product.

2. Description of the Related Art

          In recent years, various problems are becoming  
apparent in lithographic steps used in semiconductor  
manufacturing processes. As the dimensions of  
20       semiconductor devices have been scaled down, the  
demand has increased for finer pattern lithography.  
The device design rules have already scaled down to  
0.13  $\mu\text{m}$ . As a result of this, the pattern dimensions  
must be controlled with a very strict accuracy of the  
25       order of 10 nm.

          Under such a circumstance, one factor preventing  
higher accuracy in pattern formation steps is the

degrees of flatness of photomasks used in lithographic steps. With further shrinking of dimensions, the margin for the depth of focus in lithographic steps decreases. Under this circumstance, the degrees of flatness of photomasks has become non-negligible.

In general, the photomask is formed by depositing a translucent film and a shading film on a substrate of quartz. The translucent film has a large internal stress in excess of 1 GPa. This internal stress deforms the quartz substrate, deteriorating the flatness of the photomask. The deterioration of the flatness has constituted the prime cause of poor yield.

The translucent film and the shading film deposited on the substrate of quartz are etched into a desired mask pattern, whereby the photomask manufacturing process is completed. It is difficult to predict the deformation of the substrate after mask pattern formation from the internal stresses that the translucent and shading films have at the time of deposition; therefore, the flatness of the photomask cannot be controlled.

#### BRIEF SUMMARY OF THE INVENTION

In an aspect of the present invention, there is provided a photomask comprising a substrate, a translucent film selectively formed on the substrate, and a shading film selectively formed on the translucent film, wherein when the substrate,

the translucent film and the shading film have Young's moduli (MPa)  $E_0$   $E_1$  and  $E_2$ , and film thickness (m)  $d_0$ ,  $d_1$  and  $d_2$  respectively, internal stresses (MPa) of the translucent film and the shading film at room temperature are  $s_1$  and  $s_2$  respectively, a covering rate by the translucent film defined by an area in which the shading film is not formed is expressed as  $h$ , and coefficients are expressed as  $k_1 = 1.3 \times 10^{-8}$ ,  $k_2 = -9.5 \times 10^{-2}$ ,  $k_3 = 6.0 \times 10^{-7}$ , and  $k_4 = -5.2 \times 10^{-2}$  respectively, the substrate, the translucent film and the shading film satisfy a condition given by the following expression:

$$\left| \frac{1}{E_0 \cdot d_0} \cdot \left\{ h \cdot \left( k_1 \cdot \frac{s_1}{E_1 \cdot d_1} + k_2 \right) + \left( k_3 \cdot \frac{s_2}{E_2 \cdot d_2} + k_4 \right) \right\} \right| \leq 1.4 \times 10^{-4} (\text{m}^{-1})$$

In another aspect of the invention, there is provided a method of manufacturing a photomask comprising forming a translucent film and a shading film sequentially onto a surface of a substrate, measuring an internal stress in each of the translucent film and the shading film, determining whether or not a following expression is satisfied when the substrate, the translucent film and the shading film have Young's moduli (MPa)  $E_0$   $E_1$  and  $E_2$ , and film thickness (m)  $d_0$ ,  $d_1$  and  $d_2$  respectively, internal stresses (MPa) of the translucent film and the shading film at room temperature are  $s_1$  and  $s_2$  respectively,

a virtual covering rate by the translucent film after mask pattern formation defined by an area in which the shading film is not formed is expressed as  $h$ , coefficients are expressed as  $k_1 = 1.3 \times 10^{-8}$ ,  
5  $k_2 = -9.5 \times 10^{-2}$ ,  $k_3 = 6.0 \times 10^{-7}$ , and  $k_4 = -5.2 \times 10^{-2}$  respectively, and a predicted warping amount for a desired photomask after the mask pattern formation is defined as  $A$  ( $m^{-1}$ ), and

$$\left| \frac{1}{E_0 \cdot d_0} \cdot \left\{ h \cdot \left( k_1 \cdot \frac{S_1}{E_1 \cdot d_1} + k_2 \right) + \left( k_3 \cdot \frac{S_2}{E_2 \cdot d_2} + k_4 \right) \right\} \right|$$

10  $\leq A$  ( $m^{-1}$ )

removing the translucent film and the shading film selectively to be the covering rate  $h$  that satisfy the expression based on the determination result.

In still another aspect of the invention, there is  
15 provided a method of manufacturing an electronic product comprising forming a photoresist on a substrate to be processed, passing light through a photomask having a mask pattern that has a substrate, a translucent film selectively formed on the substrate  
20 and a shading film selectively formed on the translucent film to transfer the mask pattern onto the photoresist; wherein when the substrate, the translucent film and the shading film have Young's moduli (MPa)  $E_0$ ,  $E_1$  and  $E_2$ , and film thickness (m)  $d_0$ ,  
25  $d_1$  and  $d_2$  respectively, internal stresses (MPa) of the translucent film and the shading film at room

temperature are  $s_1$  and  $s_2$  respectively, a covering rate by the translucent film defined by an area in which the shading film is not formed is expressed as  $h$ , and coefficients are expressed as  $k_1 = 1.3 \times 10^{-8}$ ,  
5  $k_2 = -9.5 \times 10^{-2}$ ,  $k_3 = 6.0 \times 10^{-7}$ , and  $k_4 = -5.2 \times 10^{-2}$  respectively, the substrate, the translucent film and the shading film satisfy a condition given by the following expression:

$$\left| \frac{1}{E_0 \cdot d_0} \cdot \left\{ h \cdot \left( k_1 \cdot \frac{s_1}{E_1 \cdot d_1} + k_2 \right) + \left( k_3 \cdot \frac{s_2}{E_2 \cdot d_2} + k_4 \right) \right\} \right|$$

10  $\leq 1.4 \times 10^{-4} (m^{-1})$

developing the photoresist, and selectively processing the substrate to be processed using the photoresist as a mask.

#### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF DRAWING

15 FIG. 1 is a longitudinal section of a photomask according to a first embodiment of the present invention;

FIGS. 2A, 2B and 2C are sectional views, in the order of manufacturing steps of the photomask according  
20 to the first embodiment;

FIGS. 3A through 3F are sectional views illustrating a manufacturing steps of an electronic product using the half-tone phase shifting mask according to the first embodiment;

25 FIG. 4 shows an example of an exposure apparatus used in the first embodiment;

FIG. 5 is a flowchart illustrating a method of manufacture of a photomask according to a second embodiment of the present invention; and

FIG. 6 shows a computer system used in manufacturing a photomask according to a modification of the second embodiment.

#### DETAILED DESCRIPTION OF THE INVENTION

The embodiments of the present invention will be described hereinafter with reference to the accompanying drawings.

##### [First Embodiment]

FIG. 1 is a longitudinal section of a photomask according to a first embodiment of the present invention. As shown in FIG. 1, the photomask, indicated generally at 10, comprises a substrate 1 of quartz, a translucent film 2, and a shading film 3. The translucent film 2 and the shading film 3 are deposited on the quartz substrate 1 in the order mentioned.

The quartz substrate 1 is a transmission substrate which is square in shape and measures 152 mm on a side and about 6 mm in thickness. The translucent film 2 comprises, say, MoSiON (hereinafter referred simply to as MoSi) and is selectively formed on the quartz substrate 1 at a thickness of about 95 nm. The shading film 3 comprises, say, Cr and is selectively formed on the translucent film 2 at a thickness of about 59 nm.

In FIG. 1, an area indicated at 4 is a pattern formed area and an area indicated at 5 is a peripheral area. In the pattern formed area 4 is formed a circuit pattern to be transferred onto a wafer. The peripheral area 5 is formed in the periphery of the pattern formed area 4 to surround it and covered with the shading film 3. Thus, unwanted patterns in other than the pattern formed area can be prevented from being transferred onto the wafer.

10 In the first embodiment, the rate,  $h$ , of covering is used as one of the values representing characteristics of the photomask. A covering rate  $h$  refers to the rate at which the substrate 1 is covered with the translucent film 2 in the area where the shading film 3 is not formed and is defined by  $h =$   
15  $W_2/W_1$  where  $W_1$  is the total area of the pattern formed area 4 and  $W_2$  is the area occupied by the translucent film 2 that covers the quartz substrate 1 in the pattern formed area 4.

20 The pattern formed area 4 comprises transmission portions 4a and semi-transmission portions 4b. The transmission portions 4a comprises only the quartz substrate 1. The semi-transmission portions 4b comprises the quartz substrate 1 and the translucent  
25 film 2. The semi-transmission film 2 functions as a phase shifting layer. The phase shifting function of the semi-transmission film causes the phase of light

that passes through the transmission portions 4a  
(for example, the light transmittance is about 100%)  
and the phase of light that passes through the  
semi-transmission portions 4b (for example, the light  
5 transmittance is about 6%) to differ from each other  
(for example, by 180 degrees), which allows the pattern  
formed in the area 4 to be transferred onto the surface  
of the wafer.

Here, let the quartz substrate 1, the translucent  
10 film 2 and the shading film 3 be  $E_0$ ,  $E_1$ , and  $E_2$ ,  
respectively, in Young's modulus (MPa) and  $d_0$ ,  $d_1$ , and  
 $d_2$ , respectively, in thickness (m). Let the internal  
stresses of the translucent film 2 and the shading film  
3 at room temperature (say, 25°C) be  $s_1$  and  $s_2$ ,  
15 respectively. The covering rate by the translucent  
film 2 after the formation of mask pattern is defined  
as  $h$ . Furthermore, let constants  $k_1$ ,  $k_2$ ,  $k_3$  and  $k_4$  be  
 $k_1 = 1.3 \times 10^{-8}$ ,  $k_2 = -9.5 \times 10^{-2}$ ,  $k_3 = 6.0 \times 10^{-7}$ ,  
and  $k_4 = -5.2 \times 10^{-2}$ .

20 From consideration of relationships between mask  
substrates different in internal stress and the  
covering rates, we found that the following  
relationship exists between the aforementioned  
parameters and the radius of curvature,  $R$ , which serves  
25 as a index of the amount of warping of the substrate  
after the mask pattern formation:

$$\frac{1}{R} = \frac{1}{E_0 \cdot d_0} \cdot \left\{ h \cdot \left( k_1 \cdot \frac{S_1}{E_1 \cdot d_1} + k_2 \right) + \left( k_3 \cdot \frac{S_2}{E_2 \cdot d_2} + k_4 \right) \right\} \quad (1)$$

The absolute value of  $1/R$  in equation (1), i.e., the amount of warping of the substrate, is set such that  $|1/R| \leq 1.4 \times 10^{-4} \text{ (m}^{-1}\text{)}$ . This allows the flatness of the photomask after mask pattern formation to be kept at  $0.8 \text{ }\mu\text{m}$  or less. The flatness refers to the distance between a highest position and a lowest position.

The photomask of the present embodiment is therefore formed through the use of the quartz substrate 1, the translucent film 2 and the shading film 3 which have such parameters as satisfy equation (1).

FIGS. 2A, 2B and 2C are sectional views, in the order of steps of manufacture, of the photomask shown in FIG. 1.

As shown in FIG. 2A, first, the translucent film 2 and the shading film 3 are formed sequentially onto the surface of the quartz substrate 1. Specifically, on the surface of the quartz substrate 1 which is, for example,  $152 \text{ mm}$  on a side and about  $6 \text{ mm}$  in thickness, the translucent film 2 comprising MoSi is formed at a thickness of, say,  $95 \text{ nm}$  by means of sputtering. Next, the shading film 3 comprising Cr is formed on the translucent film 2 at a thickness of, say,  $59 \text{ nm}$  by means of sputtering. Thereby, a half-tone mask blank

is formed which is of the stacked structure of the quartz substrate 1, the translucent film 2 and the shading film 3.

5 In the sputtering of Cr to form the shading film 3, the pressure of an Ar gas is set at 11 mTorr higher than 5 mTorr, the commonly used gas pressure. The internal stresses of the translucent film 2 and the shading film 3 deposited in such a manner as described above were measured via X-ray diffraction. More  
10 specifically, the interplanar spacing of each of the MoSi and Cr films was measured through X-ray diffraction and the internal stress was calculated using the  $\sin^2\phi$  method. As a result, for the Cr film, the internal stress was 2100 MPa in the direction of  
15 tension and for the MoSi film, the internal stress was 1400 MPa in the direction of compression.

Next, for the half-tone mask blank fabricated in the above manner, we found the values of  $1/R$  using equation (1) for the case where the covering rate  $h$  by  
20 the translucent film 2 is 30%, 50%, 70%, or 100%. The calculations are indicated in Table 1.

Table 1

MoSi film			Cr film			Covering rate	1/R (calculated value) ( $\text{m}^{-1}$ )	Flatness (measured value) ( $\mu\text{m}$ )	Mask production yield
Young's modulus (GPa)	Thickness (nm)	Internal stress (MPa)	Young's modulus (GPa)	Thickness (nm)	Internal stress (MPa)				
275	95	-1400	255	59	2100	0.3	$6.66 \times 10^{-6}$	0.04	OK
275	95	-1400	255	59	2100	0.5	$-3.53 \times 10^{-5}$	0.20	OK
275	95	-1400	255	59	2100	0.7	$-7.72 \times 10^{-5}$	0.45	OK
275	95	-1400	255	59	2100	1	$-1.40 \times 10^{-4}$	0.80	OK

As shown in Table 1,  $|1/R| \leq 1.4 \times 10^{-4}(\text{m}^{-1})$  resulted for any covering rate. We therefore confirmed that desired photomasks could be produced if the covering rate was set in the range from 30 to 100%.

5       Next, a layer of positive chemically amplified resist is coated onto the surface of the shading film 3 of the resultant half-tone mask blank at a thickness of about 500 nm. Using an electron beam lithography system having an acceleration voltage of about 50 keV,  
10       a 1 G DRAM pattern with a hole size in the  $0.6 \mu\text{m}$  design rule was then drawn. The  $0.6 \mu\text{m}$  hole size is the value on the mask. When the transfer magnification of the photomask is four, the  $0.6 \mu\text{m}$  hole size corresponds to about  $0.13 \mu\text{m}$  on the wafer. After  
15       pattern drawing, the resultant structure was baked for 15 min at  $110^{\circ}\text{C}$  and then subjected to spray development with an alkaline developer solution to form a resist pattern. In this resist pattern formation process, four types of patterns such that their respective  
20       covering rates are 30%, 50%, 70%, and 100% were formed. When the covering rate is 100%, there is no need of drawing any pattern by the electron beam lithography system.

25       Next, as shown in FIG. 2B, using the resist pattern as a mask, both the shading film 3 and the translucent film 2 were etched by means of reactive ion etching techniques. A mixture of chlorine and oxygen

gases is used as the etching gas. After that, the resist layer was stripped off by ashing equipment and the mask was then cleaned by a cleaning machine. Next, the shading film 3 in the pattern formed area 4 was etched away by means of wet etching. In this manner, the half-tone phase shifting masks having covering rates of 30%, 50%, 70% and 100% were obtained (FIG. 2C). The areas where both the shading film 3 and the translucent film 2 were etched away correspond to the transmission portions 4a comprising the quartz substrate 1 only. The areas where only the shading film 3 was etched away correspond to the semitransmission portions 4b where the translucent film 3 is left on the quartz substrate 1.

The flatness of each of the half-tone phase shifting masks having covering rates of 30%, 50%, 70% and 100% manufactured in accordance with the aforementioned method was measured by an optical interferometer. The measurements are indicated in Table 1. As can be seen from Table 1, the flatness is kept at  $0.8 \mu\text{m}$  or less for any mask. Therefore, the margin for the depth of focus is allowed to increase in comparison with the prior art and the mask production yield can be expected to increase.

Reference is now made to FIGS. 3A through 3F to describe a method of manufacturing an electronic product using a half-tone phase shifting mask produced

in accordance with the aforementioned manufacturing method.

In the description which follows, an example of manufacturing a semiconductor device as an electronic product will be described.

The outline of electronic product manufacturing steps is as follows.

First, a photoresist is formed on a substrate to be processed. Next, a mask pattern of a photomask that satisfies  $|1/R| \leq 1.4 \times 10^{-4} (\text{m}^{-1})$  is transferred onto the photoresist by an exposure system. Next, the photoresist is developed and the substrate is selectively processed using the photoresist as a mask.

Hereinafter, the electronic product manufacturing steps will be described more specifically.

First, a substrate 33 to be processed is prepared which has been coated with a photoresist 34 (FIG. 3A). The substrate 33 to be processed may be any substrate on which a pattern is to be formed, such as a wafer itself, a wafer formed on top with a film or films, etc. Films formed on a wafer include semiconductor films, metal films, and insulating films. A photomask circuit pattern is transferred onto the substrate 33 using an exposure system (FIG. 3B).

An exemplary configuration of the exposure system is illustrated in FIG. 4. In the exposure system 30 shown in FIG. 4, light 31a from an illumination

optical system (light source) 31 is directed onto a photomask 10. The light 31a passed through the photomask 10 is directed onto the substrate 33 to be processed through a projection optical system 32. That  
5 is, the circuit pattern of the photomask 10 is imaged onto the photoresist 34 on the substrate 33 placed on a stage 36.

In the development process (FIG. 3C), the light-exposed portions of the photoresist 34 are dissolved  
10 with a solvent and the unexposed resist pattern is left. After the development process, the substrate 33 is baked for a given period of time at a given temperature. Next, the substrate is etched using the resist pattern as a mask (FIG. 3D), so that those  
15 exposed portions of the substrate 33 which are not covered with the photoresist 34 are selectively etched to a given depth. Thereby, the surface of the substrate 33 (including a film or films thereon) is processed into a shape corresponding to the resist  
20 pattern. After the termination of the etching process, the photoresist 34 is stripped off the substrate 33 by ashing using oxygen plasma and the resultant substrate is then cleaned (FIG. 3E).

After the termination of the above  
25 photolithography and processing, a film of a semiconductor, a metal, or an insulator is formed on the substrate 33 (FIG. 3F). A CMP or etchback process

is performed on the film 35 or on the film 35 and the substrate 33 for planarization. After that, the film 35 is processed through the same lithography process as described above. Further, the film formation and the  
5 film processing after the photolithography process are repeated in such a way that a new film is deposited on the resultant substrate and the film is then processed. Thereby, a semiconductor substrate formed with transistors, capacitors, electrodes, and interconnect  
10 lines is produced. A semiconductor part is finished by performing processes, such as dicing, mounting, bonding, sealing, etc., on the resultant semiconductor substrate.

The resultant semiconductor part is inspected  
15 through the use of an electron microscope and its characteristics, such as functions and performance, are inspected. These inspections confirmed that the production yield of semiconductor parts, such as DRAMs, could be increased significantly.

20 For comparison, the characteristics of a photomask produced by a conventional technique and the yield of semiconductor parts fabricated through the use of that photomask were measured.

A method of manufacturing a photomask using the  
25 conventional technique will be explained below.

First, on the surface of a quartz substrate 152 mm on a side and about 6 mm in thickness, a translucent

film comprising MoSi was deposited at a thickness of 95 nm by means of sputtering. Next, a shading film comprising Cr was deposited on the translucent film at a thickness of 59 nm by means of sputtering. By  
5 measuring the deformations of interplanar spacing through X-ray diffraction, the internal stress in each of the MoSi and Cr films was measured. As a result, for the MoSi film, the internal stress was 1400 MPa in the direction of compression and for the Cr film, the  
10 internal stress was 0 MPa. The large internal stress in the MoSi film warped the resultant half-tone mask blank. The flatness of the mask blank was measured by an optical interferometer to be 1.9  $\mu\text{m}$ .

A layer of positive chemically amplified resist is  
15 coated onto the surface of the half-tone mask blank at a thickness of 500 nm. A 1 GDRAM pattern with a hole size in the 0.6  $\mu\text{m}$  design rule was then drawn. The 0.6  $\mu\text{m}$  hole size is the value on the mask using an electron beam lithography system having an acceleration  
20 voltage of about 50 keV. When the transfer magnification of the photomask is four, the 0.6  $\mu\text{m}$  hole size corresponds to about 0.13  $\mu\text{m}$  on the wafer. After pattern drawing, the resultant structure was baked for 15 min at 110°C and then spray developed with  
25 an alkaline developer solution, whereby a resist pattern was formed on the mask blank.

Next, using the resist pattern as a mask, both the

MoSi film and the Cr film were etched by means of reactive ion etching techniques. As the etching gas use was made of a mixture of chlorine and oxygen gases. After that, the resist layer was stripped off the mask blank surface by ashing equipment and the mask was then cleaned by a cleaning machine. Next, the Cr film in the pattern formed area was etched away by means of wet etching. Thus, a half-tone phase shifting mask was produced.

In the mask thus produced the substrate deformation due to the internal stress in the MoSi film remains even after the pattern formation. The covering rate by the MoSi film on the mask varies with the pattern shape and the deformation of the substrate varies depending on the covering rate. Photomasks having MoSi covering rates of 30, 50, 70 and 100% were produced and their flatnesses were measured through the use of an optical interferometer. The measurements are indicated in Table 2 below.

Table 2

MoSi film		Cr film			Covering rate	1/R (calculated value) (m <sup>-1</sup> )	Flatness (measured value) ( $\mu$ m)	Mask production yield
Young's modulus (GPa)	Thick-ness (nm)	Internal stress (MPa)	Young's modulus (GPa)	Thick-ness (nm)				
275	95	-1400	255	59	0	$-1.77 \times 10^{-4}$	-1.02	NG
275	95	-1400	255	59	0	$-2.19 \times 10^{-4}$	-1.26	NG
275	95	-1400	255	59	0	$-2.61 \times 10^{-4}$	-1.51	NG
275	95	-1400	255	59	0	$-3.24 \times 10^{-4}$	-1.87	NG

The  $1/R$  values obtained from equation (1) for those photomasks are also indicated in Table 2. The Young's modulus is 73 GPa for quartz substrate, 275 GPa for MoSi film, and 255 GPa for Cr film. For any  
5 covering rate,  $|1/R|$  exceeds  $1.4 \times 10^{-4}$  and the flatness exceeds  $0.8 \mu\text{m}$ . As can be seen from comparison with Table 1, the absolute value of the flatness is larger than in the present embodiment. As  
10 a result of manufacturing of semiconductor parts in accordance with the semiconductor part manufacturing method of the present embodiment using the photomask produced in accordance with the conventional method, the manufacturing yield reduced.

With the conventional technique, the amount of  
15 warping is known after the mask pattern has been formed. When, therefore, a photomask such that its amount of warping was too large to be used was produced, the mask pattern formation process went in vain. Under such a circumstance, means for predicting  
20 the amount of warping after mask pattern formation has been expected. As described above, according to the present embodiment, photomasks good in flatness were produced. The manufacturing yield of semiconductor products such as DRAMs manufactured using such  
25 photomasks increases significantly in comparison with the case where the conventional technique is used.

As described above, according to the present

embodiment, a photomask good in flatness can be provided. Accordingly, the margin for the depth of focus at wafer exposure time increases remarkably, allowing the manufacturing yield of semiconductor devices, such as DRAMs, to be increased significantly.

[Second Embodiment]

The second embodiment of the present invention is a modification of the first embodiment and relates to a method of manufacturing a photomask. More specifically, the second embodiment relates to a photomask manufacturing method which allows the amount of warping of a mask substrate after mask pattern formation to be controlled to within a desired amount. In the second embodiment, corresponding components to those in the first embodiment are denoted by like reference numerals and detailed descriptions thereof are omitted.

Hereinafter, the photomask manufacturing method according to the second embodiment will be described with reference to a flowchart shown in FIG. 5.

First, on the surface of a quartz substrate 1 which is 152 mm on a side and about 6 mm in thickness, a translucent film 2 made of MoSi is deposited at a thickness of, say, 95 nm by means of sputtering. Next, a shading film 3 made of Cr is deposited on the translucent film 2 at a thickness of, say, 59 nm by means of sputtering (S51). Thereby, a half-tone mask

blank is formed which is the stacked structure of the quartz substrate 1, the translucent film 2 and the shading film 3.

In the sputtering process of Cr, the Ar gas pressure is set to  $P_1$  to  $P_5$ . Here,  $P_1 = 7$  mTorr,  $P_2 = 8$  mTorr,  $P_3 = 13$  mTorr,  $P_4 = 18$  mTorr, and  $P_5 = 20$  mTorr. Thus, five types of half-tone mask blanks are produced according to five levels of Ar gas pressure at the Cr sputtering. The internal stress in each of the translucent film 2 and the shading film 3 is measured using X-ray diffraction techniques (S52). The interplanar spacing of each of the MoSi and Cr films is measured by X-ray diffraction. Calculations of the internal stress using the  $\sin^2\phi$  method showed that the internal stress in the MoSi film was 1400 GPa in the direction of compression for all of the five types of mask blanks and the internal stress in the Cr film was 500 MPa, 1050 MPa, 2750 MPa, 4400 MPa, and 5000 MPa in the direction of tension for the five types of mask blanks.

Next, the  $1/R$  values are calculated (S53). Specifically, the resultant internal stresses in the translucent film 2 and the shading film 3 and a virtual covering rate  $h$  after mask pattern formation are substituted into equation (1) described in the first embodiment. The Young's moduli of the quartz substrate 1, the translucent film 2 and the shading film 3 are

73 GPa, 275 GPa, and 255 GPa, respectively. The values for  $1/R$  were calculated based on equation (1) for each of the five types of mask blanks. The calculations are indicated in Tables 3 and 4 below.

Table 3

Shading film Ar gas pressure (mTorr)	MoSi film			Cr film			Virtual covering rate	1/R (calculated value) (m <sup>-1</sup> )	Decision result $\leq$ $1.4 \times 10^{-4}$	Decision result $\leq$ $0.87 \times 10^{-4}$
	Young's modulus (GPa)	Thick- ness (nm)	Internal stress (MPa)	Young's modulus (GPa)	Thick- ness (nm)	Internal stress (MPa)				
P <sub>1</sub> =7	275	95	-1400	255	59	500	0.3	$-1.33 \times 10^{-4}$	0	x
	275	95	-1400	255	59	500	0.4	$-1.54 \times 10^{-4}$	x	x
	275	95	-1400	255	59	500	0.5	$-1.75 \times 10^{-4}$	x	x
	275	95	-1400	255	59	500	0.6	$-1.96 \times 10^{-4}$	x	x
	275	95	-1400	255	59	500	0.7	$-2.17 \times 10^{-4}$	x	x
	275	95	-1400	255	59	500	0.8	$-2.38 \times 10^{-4}$	x	x
	275	95	-1400	255	59	500	0.9	$-2.59 \times 10^{-4}$	x	x
	275	95	-1400	255	59	500	1	$-2.80 \times 10^{-4}$	x	x
P <sub>2</sub> =8	275	95	-1400	255	59	1050	0.3	$-8.51 \times 10^{-5}$	0	0
	275	95	-1400	255	59	1050	0.4	$-1.06 \times 10^{-4}$	0	x
	275	95	-1400	255	59	1050	0.5	$-1.27 \times 10^{-4}$	0	x
	275	95	-1400	255	59	1050	0.6	$-1.48 \times 10^{-4}$	x	x
	275	95	-1400	255	59	1050	0.7	$-1.69 \times 10^{-4}$	x	x
	275	95	-1400	255	59	1050	0.8	$-1.90 \times 10^{-4}$	x	x
	275	95	-1400	255	59	1050	0.9	$-2.11 \times 10^{-4}$	x	x
	275	95	-1400	255	59	1050	1	$-2.32 \times 10^{-4}$	x	x
P <sub>3</sub> =13	275	95	-1400	255	59	2750	0.3	$6.35 \times 10^{-5}$	0	0
	275	95	-1400	255	59	2750	0.4	$4.25 \times 10^{-5}$	0	0
	275	95	-1400	255	59	2750	0.5	$2.15 \times 10^{-5}$	0	0
	275	95	-1400	255	59	2750	0.6	$5.55 \times 10^{-7}$	0	0
	275	95	-1400	255	59	2750	0.7	$-2.04 \times 10^{-5}$	0	0
	275	95	-1400	255	59	2750	0.8	$-4.14 \times 10^{-5}$	0	0
	275	95	-1400	255	59	2750	0.9	$-6.24 \times 10^{-5}$	0	0
	275	95	-1400	255	59	2750	1	$-8.33 \times 10^{-5}$	0	0

Table 4

Shading film Ar gas pressure (mTorr)	MoSi film			Cr film			Virtual covering rate	1/R (calculated value) (m <sup>-1</sup> )	Decision result $\leq$ 1.4×10 <sup>-4</sup>	Decision result $\leq$ 0.87×10 <sup>-4</sup>
	Young's modulus (GPa)	Thick- ness (nm)	Internal stress (MPa)	Young's modulus (GPa)	Thick- ness (nm)	Internal stress (MPa)				
P <sub>4</sub> =18	275	95	-1400	255	59	4400	0.3	2.08×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	4400	0.4	1.87×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	4400	0.5	1.66×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	4400	0.6	1.45×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	4400	0.7	1.24×10 <sup>-4</sup>	o	x
	275	95	-1400	255	59	4400	0.8	1.03×10 <sup>-4</sup>	o	x
	275	95	-1400	255	59	4400	0.9	8.19×10 <sup>-5</sup>	o	o
	275	95	-1400	255	59	4400	1	6.09×10 <sup>-5</sup>	o	o
	275	95	-1400	255	59	5000	0.3	2.60×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	5000	0.4	2.39×10 <sup>-4</sup>	x	x
P <sub>5</sub> =20	275	95	-1400	255	59	5000	0.5	2.18×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	5000	0.6	1.97×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	5000	0.7	1.76×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	5000	0.8	1.55×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	5000	0.9	1.34×10 <sup>-4</sup>	o	x
	275	95	-1400	255	59	5000	1	1.13×10 <sup>-4</sup>	o	x
	275	95	-1400	255	59	5000	0.3	2.60×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	5000	0.4	2.39×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	5000	0.5	2.18×10 <sup>-4</sup>	x	x
	275	95	-1400	255	59	5000	0.6	1.97×10 <sup>-4</sup>	x	x

Next, decisions are made as to whether or not the  $|1/R|$  values for the five types of mask blanks are within the range of the desired warping amount  $A$  ( $m^{-1}$ ) ( $A$ : the predicted amount of warping) after mask pattern formation (S54). The desired warping amount  $A$  can be set freely according to the required accuracy of pattern dimensions. In the present embodiment, decisions were made as to whether or not the  $|1/R|$  values were  $1.4 \times 10^{-4}(m^{-1})$  or less corresponding to the  $0.13 \mu m$  rule on wafer and  $0.87 \times 10^{-4}(m^{-1})$  or less corresponding to the  $0.10 \mu m$  rule on wafer. The virtual covering rate  $h$  was set in the range of 30 to 100%. Specifically,  $h$  was set to 30, 40, 50, 60, 70, 80, 90, and 100%. With a photomask for which  $h = 100\%$ , the pattern formed area 4 is fully covered with the translucent film 2. Although such a photomask is not used in actual pattern exposure, the  $|1/R|$  values in the case of  $h = 100\%$  were calculated for comparison.

The results in the decision step are also indicated in Tables 3 and 4. That is, the results of decisions in the case where the desired warping amount  $A$  is  $1.4 \times 10^{-4}(m^{-1})$  or less and the results of decisions in the case where the desired warping amount  $A$  is  $0.87 \times 10^{-4}(m^{-1})$  or less are indicated. With the mask blanks that are marked  $\bigcirc$  in Tables 3 and 4, it is expected that the  $|1/R|$  values will fall within

the range of the desired warping amount after mask pattern formation. For the others, it is expected that the  $|1/R|$  values will go beyond the desired warping amount after mask pattern formation.

5           As shown in Tables 3 and 4, it can be decided that, with the mask blanks in which the internal stress in the Cr shading film 3 is 500 MPa, the photomask warping amount after mask pattern formation becomes  $1.4 \times 10^{-4}(\text{m}^{-1})$  or less when the covering rate by the  
10 translucent film 2 is 30%. With the mask blanks in which the internal stress in the Cr shading film 3 is 1050 MPa, it can be decided that the photomask warping amount after mask pattern formation becomes  $1.4 \times 10^{-4}(\text{m}^{-1})$  or less when the covering rate by the  
15 translucent film 2 is in the range of 30 to 50%. With the mask blanks in which the internal stress in the Cr shading film 3 is 2750 MPa, it can be decided that the photomask warping amount after mask pattern formation becomes  $1.4 \times 10^{-4}(\text{m}^{-1})$  or less when the covering rate  
20 by the translucent film 2 is in the range of 30 to 100%. With the mask blanks in which the internal stress in the Cr shading film 3 is 4400 MPa, it can be decided that the photomask warping amount after mask pattern formation becomes  $1.4 \times 10^{-4}(\text{m}^{-1})$  or less when  
25 the covering rate by the translucent film 2 is in the range of 70 to 100%. With the mask blanks in which the internal stress in the Cr shading film 3 is 5000 MPa,

it can be decided that the photomask warping amount after mask pattern formation becomes  $1.4 \times 10^{-4}(\text{m}^{-1})$  or less when the covering rate by the translucent film 2 is in the range of 90 to 100%.

5           From these it will be understood that, if the internal stress of the Cr shading film 3 at room temperature is in the range of 500 MPa to 5 GPa, the choice of mask patterns allows  $|1/R| \leq 1.4 \times 10^{-4}$  and a flatness of  $0.8 \mu\text{m}$  or less to be realized.

10           Furthermore, with the mask blanks in which the internal stress in the Cr shading film 3 is 1050 MPa, it can be decided that the photomask warping amount after mask pattern formation becomes  $0.87 \times 10^{-4}(\text{m}^{-1})$  or less when the covering rate by the translucent film 2 is 30%. With the mask blanks in which the internal stress in the Cr shading film 3 is 2750 MPa, it can be decided that the photomask warping amount after mask pattern formation becomes  $0.87 \times 10^{-4}(\text{m}^{-1})$  or less when the covering rate by the translucent film 2 is in the range of 30 to 100%. With the mask blanks in which the internal stress in the Cr shading film 3 is 4400 MPa, it can be decided that the photomask warping amount after mask pattern formation becomes  $0.87 \times 10^{-4}(\text{m}^{-1})$  or less when the covering rate by the translucent film 2 is in the range of 90 to 100%.

25           From these it will be understood that, if the internal stress of the Cr shading film 3 at

room temperature is in the range of 1000 MPa to 4500 MPa, the choice of mask patterns allows  $|1/R| \leq 0.87 \times 10^{-4}$  and a flatness of 0.5  $\mu\text{m}$  or less to be realized.

5           Next, patterning is performed on the half-tone mask blanks with the Cr films by means of lithographic techniques (S55). This patterning process corresponds to the process shown in FIGS. 2A, 2B and 2C. Thereby, photomasks formed with desired mask patterns are  
10           finished. At this point, the translucent film 2 and the shading film 3 are selectively removed so that the resultant mask patterns have covering rates for which the warping amount has been decided to be the desired value or less in step S54. This obviates the necessity  
15           of producing photomasks such that the warping amount exceeds the desired amount, allowing the photomask manufacturing yield to be increased.

             Specifically, for mask blanks in which the internal stress of the Cr shading film 3 is 2750 MPa,  
20           mask patterns in which the covering rates by the translucent film 2 are 30, 50, 70, and 90% were formed. For mask blanks in which the internal stress of the Cr shading film 3 is 1050 MPa, mask patterns in which the covering rates by the translucent film 2 are 30 and 50%  
25           were selectively formed. For mask blanks in which the internal stress of the Cr shading film 3 is 500 MPa, a mask pattern in which the covering rate by the

translucent film 2 is 30% was selectively formed. For mask blanks in which the internal stress of the Cr shading film 3 is 4400 MPa, mask patterns in which the covering rates by the translucent film 2 are 70 and 90% were selectively formed. For mask blanks in which the internal stress of the Cr shading film 3 is 5000 MPa, a mask pattern in which the covering rate by the translucent film 2 is 90% was selectively formed.

Specifically, in the lithography process, a layer of positive chemically amplified resist is coated onto the surface of each of the mask blanks, i.e., onto the surface of the shading film 3, at a thickness of 500 nm. Using an electron beam lithography system having an acceleration voltage of 50 keV, patterns were then drawn on the resist layers of the mask blanks. After the pattern drawing, the mask blanks were baked for 15 min at 110°C and then spray developed with an alkaline developer solution, whereby resist patterns were formed on the surfaces of the mask blanks.

Next, using the resist patterns as etching masks, both the shading film 3 and the translucent film 2 were etched by means of reactive ion etching techniques. As the etching gas use was made of a mixture of chlorine and oxygen gases. After that, the resist layers were stripped off the mask blank surfaces by ashing equipment and the masks were then cleaned by a cleaning machine. Next, the shading film 3 in the pattern

formed area of each mask blank was etched away by means of wet etching. Thus, half-tone phase shifting masks were produced.

5       The warping amount and the flatness of each of the photomask thus produced were measured by an optical interferometer. The measurements are indicated in Table 5 below.

Table 5

MoSI film			Cr film			Covering rate	Warping amount (measured value) ( $\text{m}^{-1}$ )	Flatness (measured value) ( $\mu\text{m}$ )
Young's modulus (GPa)	Thickness (nm)	Internal stress (MPa)	Young's modulus (GPa)	Thickness (nm)	Internal stress (MPa)			
275	95	-1400	255	59	500	0.3	$-1.3 \times 10^{-4}$	0.77
275	95	-1400	255	59	1050	0.3	$-8.5 \times 10^{-5}$	0.49
275	95	-1400	255	59	1050	0.5	$-1.3 \times 10^{-4}$	0.73
275	95	-1400	255	59	2750	0.3	$6.3 \times 10^{-5}$	0.37
275	95	-1400	255	59	2750	0.5	$2.2 \times 10^{-5}$	0.12
275	95	-1400	255	59	2750	0.7	$-2.0 \times 10^{-5}$	0.12
275	95	-1400	255	59	2750	0.9	$-6.2 \times 10^{-5}$	0.36
275	95	-1400	255	59	4400	0.7	$1.2 \times 10^{-4}$	0.77
275	95	-1400	255	59	4400	0.9	$8.2 \times 10^{-5}$	0.47
275	95	-1400	255	59	5000	0.9	$1.3 \times 10^{-4}$	0.78

As can be seen, the warping amount was below  
1.4  $\times 10^{-4}$ (m<sup>-1</sup>) for all the photomasks. Thus, it  
becomes possible to select mask blanks the warping  
amount of which after mask pattern formation becomes a  
5 desired amount or less. That is, it becomes possible  
to predict the warping amount of a photomask after  
pattern formation before it is finished, allowing the  
mask production yield to be increased significantly.

Heretofore, there has been no means for predicting  
10 the warping amount of a photomask after mask pattern  
formation. Therefore, the mask warping amount has had  
to be measured after mask pattern formation in order to  
make a decision of whether or not it is in the range of  
a desired amount. For photomasks in which the warping  
15 amount is too large to be used, the mask formation  
process has been in vain. The manufacturing cost of  
mask blanks up to the mask pattern formation is several  
hundreds of thousands of yen, while the mask pattern  
formation costs several millions of yen. The present  
20 embodiment has allowed the mask manufacturing cost to  
be reduced greatly.

The photomasks produced in accordance with the  
present embodiment are 0.8  $\mu$ m or less in flatness,  
thus increasing considerably the margin for the depth  
25 of focus at wafer exposure time and improving  
significantly the manufacturing yield of semiconductor  
devices such as DRAMs. Of the photomasks produced in

accordance with the present embodiment, the following masks (1), (2) and (3) are 0.5  $\mu\text{m}$  or less in flatness.

(1) A photomask having a pattern of the translucent film 2 formed at a covering rate of 30% on a mask blank in which the internal stress in the Cr shading film is 1050 MPa.

(2) Photomasks having patterns of the translucent film 2 formed at covering rates of 30, 50, 70 and 90% on mask blanks in which the internal stress in the Cr shading film is 2750 MPa.

(3) A photomask having a pattern of the translucent film 2 formed at a covering rate of 90% on a mask blank in which the internal stress in the Cr shading film is 4400 MPa.

Therefore, the margin for the depth of focus at wafer exposure time increases considerably, and the manufacturing yield of semiconductor devices, such as DRAMs, which have fine patterns in the 0.10  $\mu\text{m}$  design rule on wafer increases significantly.

Using photomasks produced in the above manner, electronic products can be fabricated in accordance with such steps as shown in FIGS. 3A to 3F in the first embodiment.

The calculation of the 1/R values in step S53 and the decision in step S54 may be made manually by humans or automatically by a computer.

For automatic calculation and decision, such

a computer system as shown in FIG. 6 can be used. This computer system is constructed from a processor 61, an input device 62, an output device 63, a database 64, and a communications interface 65. The input device 62,  
5 the output device 63, the database 64 and the communications interface 65 are connected to the processor 61. The processor 61 is implemented by a CPU by way of example.

The measurements in step S52 are entered into the  
10 computer system by an operator through the input device 62 including a keyboard and a mouse. The processor 61 reads the equation (1) from the database 64 and automatically calculates a value for  $1/R$ . The absolute value of the  $1/R$  value thus obtained is compared in the  
15 processor 61 with a desired amount A of warping.

The warping amount A may be input through the input device 62. When  $|1/R|$  is less than the desired warping amount A, the output device 63, such as a CRT, outputs the decision that the flatness is less than a  
20 desired value. Thus, automatic prediction of the warping amounts of photomasks is made possible. Data entered through the input device 62 and data stored in the database 64 may be received from the outside through the communications interface 65.

25 A program which allows the processor 61 to carry out the automatic processing may be recorded on a recording medium. In that case, a recording medium

reading apparatus connected to the processor 61 will read the program from the recording medium to cause the processor 61 to carry out the automatic decision processing.

5           The present invention is not limited to the embodiments described above.

          Although the embodiments have been described as the substrate 1, the translucent film 2 and the shading film 3 being made of quartz, MoSi and Cr, respectively,  
10           other materials may be also applicable to the photomasks. For example, although the translucent film 2 used in the embodiments is about 6% in light transmittance, this is not restrictive. It is only required that the translucent film 2 be higher than the  
15           shading film 3 and lower than the substrate 1 in light transmittance.

          Although the embodiments have been described as using the inventive photomasks in manufacturing semiconductor devices, they can be used in  
20           manufacturing electronic products other than semiconductor devices.

          The method of manufacturing the photomask of the present embodiments is not limited to the process shown in FIGS. 2A, 2B and 2C. For example, in the step shown  
25           in FIG. 2C or in the subsequent step, trenches of a desired depth may be formed into the surface of the quartz substrate 1 which is exposed as the result of

the shading film 3 and the translucent film 2 being removed. This allows the phase of light passed through the transmission portions 4a and the phase of light passed through the semitransmission portions 4b to be controlled.

According to the present embodiment, as described above, a photomask having a desired flatness can be provided.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspect is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.